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THESIS

THE IMPACT OF RECHARGEABLE BATTERIES: QUANTIFYING THE COST AND WEIGHT FOR A MARINE INFANTRY BATTALION

by

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December 2011

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THE IMPACT OF RECHARGEABLE BATTERIES: QUANTIFYING THE COST AND WEIGHT FOR A MARINE INFANTRY BATTALION

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ABSTRACT

Since the implementation of distributed operations with a higher density of tactical field radios, optics and electrical tactical equipment, the demand for batteries has increased significantly. While advances in technology have increased the lethality of Department of Defense (DoD) forces, sustainment and increased resupply convoys have increased the risk of logistical support and costs. This thesis examines the viability, cost savings, and operational weight associated with the use of rechargeable batteries.

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LIST OF ACRONYMS AND ABBREVIATIONS

BCT	Brigade Combat Team
CDD	Complete Discharge Device
CONUS	Continental United States
DLA	Defense Logistics Agency
DoD	Department of Defense
DOS	Days of Supply
FBCB	Fully Burdened Cost of Batteries
FBCF	Fully Burdened Cost of Fuel
FBC	Fully Burdened Cost
FY11	Fiscal Year 2011
HAZMAT	Hazardous Material
HF	High Frequency
HW	Hazardous Waste
IRB	Impact of Rechargeable Batteries
JRTC	Joint Readiness Training Center
$LiSO_2$	Lithium Sulfur Dioxide
MCCOC	Marine Corps Communication Officer’s Course
MEF	Marine Expeditionary Force
MOOTWA	Military Operations Other Than War
NHSW	Nonhazardous Solid Waste
NiMH	Nickel Metal Hydride
O&M	Operation and Maintenance
O&S	Operation and Support
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PEI	Principal End Items
POWER	Power Optimizer for the Warfighter’s Energy Requirement
RDT&E	Research Development Test and Evaluation
ROI	Return on Investment

SDC	Secondary Destination Charge
SPACES	Solar Portable Alternative Communications Energy System
SPC	Suitcase Portable Charger
TO&E	Table of Organization and Equipment
UHF	Ultra High Frequency
VHF	Very High Frequency
VMC	Vehicle Mounted Charger

EXECUTIVE SUMMARY

The implementation of distributed operations has resulted in greater demand for tactical field radios, optics and electrical tactical equipment, which consume large quantities of batteries. Rechargeable batteries present the opportunity to reduce life cycle costs, such as procurement, operation and support (O&S) and disposal costs. The primary objectives of this thesis are to develop a model for analyzing the impact of rechargeable batteries (IRB) for use by decision makers, and to compute the cost and weight associated with using rechargeable and non-rechargeable batteries needed to support a Marine Corps infantry battalion.

Each rechargeable battery costs and weighs more than its non-rechargeable counterpart; however, units may carry fewer of them to accomplish the same mission. Using rechargeable batteries saves money, reduces weight, reduces hazardous waste, and reduces resupply convoys, which results in fuel savings and lower risk to the force. The long-term savings associated with using rechargeable batteries increases as a function of the number of times they are recharged.

The model shows that the greater the daily demand for batteries, the greater the savings from using rechargeable batteries. As daily demand for batteries increases, the return on the investment in rechargeable batteries may be measured either in classic financial management terms or in saved “days of supply (DOS)” of batteries needed to operate. Rechargeable batteries are reliable and designed to be recharged 224 to 1,000 times. Furthermore, the savings are compounded each time the battery is recharged. Under a 30-day deployment scenario, it is estimated that three DOS of batteries (recharged ten times) may result in a savings of $174,418.

Rechargeable batteries reduce life cycle costs, which generate savings by replacing recurring costs with a single purchase, transportation, and disposal cost. Over the course of 30 days, the total battery weight that is carried by the unit is reduced by 80% compared to non-rechargeable batteries. The environmental impact is a savings of 3,512 lbs of potentially hazardous solid waste (1,665 cubic feet). Most of the savings

associated with the use of rechargeable batteries will be experienced by the operational battalion that consumes them while the transportation and disposal savings will be experienced by supporting units and base organizations. During the scenario, all investment costs are recovered, as well as the ROI of 34 percent. ROI continues to increase favorably with each recharge until the battery is no longer serviceable.

The Marine Corps and other services should implement policies to use rechargeable batteries when operationally feasible. Solar panels work well with rechargeable batteries and represent an opportunity to further reduce weight, fuel consumption, and resupply convoys if fielded in greater numbers. Future rechargeable batteries should be required to weigh less, last longer, and operate existing systems. Additionally, the Department of Defense should endeavor to increase the commonality of rechargeable batteries across Services and systems.

Using rechargeable batteries is one step among many that can be taken now that will save money, reduce weight, save lives, and reduce resource consumption. Rechargeable batteries will increase energy independence and reduce DoD resource vulnerability, risk of uncertainty, and future costs and budgets.

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I. INTRODUCTION

A. INCREASED DEMAND FOR RADIOS: PRE-OEF/OIF AND POST-OEF/OIF COMMUNICATIONS

This chapter introduces the changes to infantry battalion operations and logistical support. Prior to the onset of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF), Marine Corps infantry battalions had fewer tactical high frequency (HF), very high frequency (VHF), and ultra-high frequency (UHF) radios. World threats, military operations other than war (MOOTWA), small-scale conflicts, humanitarian operations, and technology led to the evolutionary concept of distributed operations. Distributed Operations involved units smaller than the infantry battalion, such as companies, platoons, squads, and teams conducting operations farther and more frequently from the battalion main support area. Communication is essential, so more tactical radios were fielded to allow better communication with the smaller operating forces. The quantity of HF, VFH, and UHF radios increased from 78 to 114 (MCCOC).

B. TYPE 90 FAMILY OF BATTERIES

1. Non-Rechargeable Batteries

The HF, VHF, and UHF radios are powered by batteries when carried or "man packed"—that is, not mounted in a vehicle, standing electrical grid, or generator. These batteries are in the Type 90 family of batteries. Each battery meets certain voltage, amperage, size, and connector requirements. The BA-5590 is called the "workhorse" of military batteries because of the numerous communication and weapons systems they power. The BA-5590 is a 12v 15-ampere lithium sulfur dioxide ($LiSO_2$) weighing 2.3 lbs (see Appendix A for more detailed information regarding the BA-5590 battery).

2. Rechargeable Batteries

The BB-390 battery is a rechargeable nickel metal hydride (NiMH) battery designed to be a "drop in" replacement for disposable BA-5590 batteries. The BB-390 battery was much heavier than the BA-5590 battery, weighing 3.9 lbs. In addition to the

increased weight, the BB-390 had only 60–80% run time compared to the lighter BA-5590 battery (POWER). See Appendix B for additional information on the BB-2590 and Appendix C for the details on the BB-390.

The BB-2590 is a fairly new rechargeable battery. The BB-2590 was built as a drop in replacement for BA-5590 batteries in most applications. The BB-2590 is a lithium ion (Li-Ion) battery. The BB-2590 weighs 3.2 lbs and has 97% of the run time compared to the BB-2590 (POWER). The BB-2590 battery has a four-year warranty from date of manufacture and is designed to be used between 224 and 1,000 times (Bren-Ttronics, personal communication, April 23, 2011). A test by L-3 Communications has not found a battery that has failed during the first four years of heavy laboratory and controlled field tests (M. Bissonnette, personal communication, May 2, 2011). It is reasonable to assume that an infantry battalion would get multiple uses from a single rechargeable battery.

3. Demand for XX90 Batteries

As the quantity of radios increased, the demand for batteries increased consequently. The estimated daily demand for BA-5590 batteries increased from 84 to 182 per day (MCCOC).

According to previous studies and data from the Second Marine Expeditionary Force (II MEF), Type 90 series batteries constitute 95% of battery demand. In FY10, $3,015,924 was spent on XX90 series batteries to support II MEF and combat operations in Afghanistan. Of that, $2,109,906, or 67% was spent on non-rechargeable XX90 batteries (II MEF spreadsheet).

C. METHODOLOGY

Equipment used by DoD have varying life cycle costs. Figure 1 displays the abstract costs associated with each phase of the life cycle: research development test and evaluation (RDT&E), production, operating and support (O&S) also called operation and maintenance (O&M), and disposal.

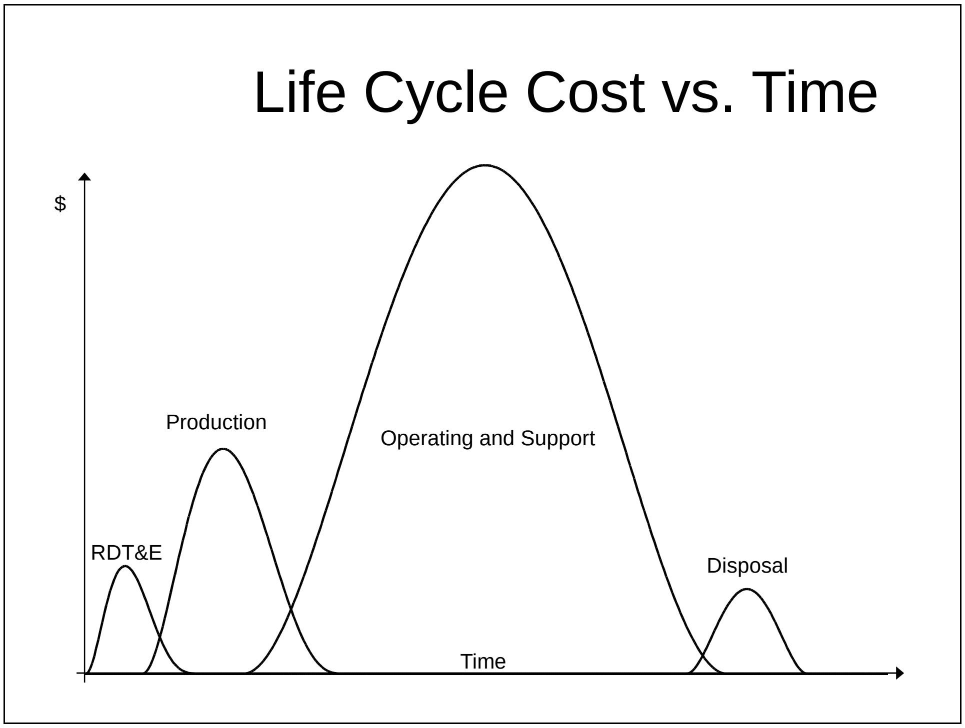

Figure 1. Life Cycle Costs Over Time (From Operations Analysis-4702 [OA-4702], 2010)

The author believes that the larger production costs of rechargeable batteries will be offset by the reduced O&S and disposal costs, which are higher for disposable batteries.

D. LIMITS OF RESEARCH

Because tactical operations vary greatly, a model was developed based upon a simplified training exercise to compare the costs associated with using rechargeable batteries versus the cost of using non-rechargeable batteries. The model uses basic requirements for a non-deployed Marine Corps infantry battalion conducting training operations in and around Marine Corps Base Twenty-nine Palms, California, for 30 days.

The data used in the model to describe battery usage was derived from the Table of Organization and Equipment (TO&E; U.S. Marine Corps, 2011) for the standard Marine Corps infantry battalion and instruction given by Marine Corps Communication Officers Course (MCCOC, 2010). The TO&E provides the number of radios that use XX90-series batteries. Currently, the battalion uses AN/PRC-117F, AN/PRC-119F, and

AN/PRC 150 radio systems, which are considered the principal end items (PEIs) and it was assumed that 30 days of battalion fire and maneuver exercises would be conducted that would constitute the overall battery demand.

The U.S. Army Communication and Electronics Command (CECOM) developed a spreadsheet model called Power Optimizer for the Warfighter's Energy Requirement (POWER) that is used to determine battery requirements. The POWER version 1.3f, which provides detailed performance information for the BA-5590 and BB-2590 batteries, was used to set parameters in the model of the U.S. Marine Corps infantry battalion. Appendix D describes POWER and how it was used to verify battery demand for each PEI.

II. BACKGROUND

A. FULLY BURDENED COSTING

The IRB builds upon previous cost analysis for commodities, such as fuel and non-rechargeable batteries. The fully burdened cost of fuel (FBCF) Corely (2009) lays the groundwork for this thesis. The FBCF considers the indirect costs associated with transportation of fuel to the end user compared to the budgeted price of fuel that planners typically use to report fuel costs. Corley validated “previous research efforts that contend the cost to deliver, store and protect the energy and its logistics tail can be many times greater than the commodity price of fuel alone” (Corley, 2009). The author examined additional costs (or “burdens”) associated with delivering fuel to the end user, which include, but are not limited to, security, manpower, and delivery assets.

As more resources are used to transport a commodity such fuel, batteries, or water additional costs are incurred that should be budgeted. Kiper et al. (2010) investigated the life cycle costs associated with the BA-5590 battery in both a CONUS and OCONUS scenario. The authors noted that disposal and transportation costs were significant with disposal being the largest cost driver in the peacetime, CONUS, scenario and established that rechargeable batteries may reduce acquisition (or purchase costs), as well as transportation and disposal costs. However, the IRB considers rechargeable batteries to be durable goods rather than a consumable commodity.

B. MANAGEMENT OF WASTE

Booz Allen Hamilton (2003) investigated the pollution and hazardous waste generated by non-rechargeable BA-5590 batteries, and found that rechargeable nickel metal hydride NiMH BB-390 batteries would effectively prevent pollution concerns, as well as reduce life cycle and environmental compliance costs associated with $LiSO_2$ waste. The authors find that by employing pollution prevention (P2) opportunities, “the Army’s cost for battery management can be greatly reduced” (Booz Allen Hamilton, 2003).

Additionally, Booz Allen Hamilton (2003) find that “[w]hile NiMH batteries initially are more expensive, if used properly their life cycle costs are lower and they can greatly reduce hazardous waste (HW) compliance issues,” as well as solid waste and hazardous waste disposal costs. At the time the study was conducted, the BB-390 battery was the only rechargeable battery available approved to replace the BA-5590. As an extension of this study, the BB-2590 has replaced the BB-390 as the rechargeable battery of choice and similarly does not contain potentially hazardous $LiSO_2$.

C. OPERATIONAL USE OF PREVIOUS RECHARGEABLE BATTERIES

Army Brigade Combat Team (BCT) 504 conducted a training exercise at Ft. Polk, LA during 2002. The BCT was unable to purchase enough BA-5590 batteries. Due to shortages stemming from Operation Enduring Freedom, all available BA-5590 batteries were sent to deployed units. The BCT adapted by using only BB-390 rechargeable batteries during their exercise. The BCT Signal Officer, Maj. Dedham stated in his after action report that “[t]he use of rechargeable batteries instead of BA-5590s at JRTC 02-07 was successful. There were no reports or indications that systems failed because of a lack of batteries.”

Additionally, Dedham stated in the after action report that resupply and charging plans were critical to the successful employment of rechargeable batteries. The BB-390 had only 60–80% of the run time compared to a BA-5590, whereas the BB-2590 has approximately 97% of the run time. The chargers available at that time charged fewer batteries than current systems. The BCT used a ratio of 4:1 BB-390 to BA-5590 throughout the exercise. Because of the BB-2590’s longer run time and increased charging capacity, the IRB estimates a 3:1 ratio of BB-2590s to each BA-5590 required.

III. IMPACT OF RECHARGEABLE BATTERY METHODOLOGY

A. INTRODUCTION

This chapter describes the methodology used to compare costs elements and weights of non-rechargeable versus rechargeable batteries. Building upon the work of Kiper, Hughley, and McClellan (2010), this thesis quantifies the Impact of Rechargeable Batteries (IRB).

The IRB is defined as the difference between the following.

- The cost of non-rechargeable batteries from the Department of Defense Logistics Agency (DLA), including the additional costs of replacing the non-rechargeable batteries, transportation costs
- Rechargeable batteries and necessary charging equipment
- Weight comparison between non-rechargeable batteries and rechargeable batteries with recharging equipment

The IRB methodology is applied to a peacetime scenario of a Marine Corps infantry battalion to determine if there are differences in cost and weight of using rechargeable batteries compared to non-rechargeable batteries. Figure 2 is a graphical representation of the methodology used in this thesis.

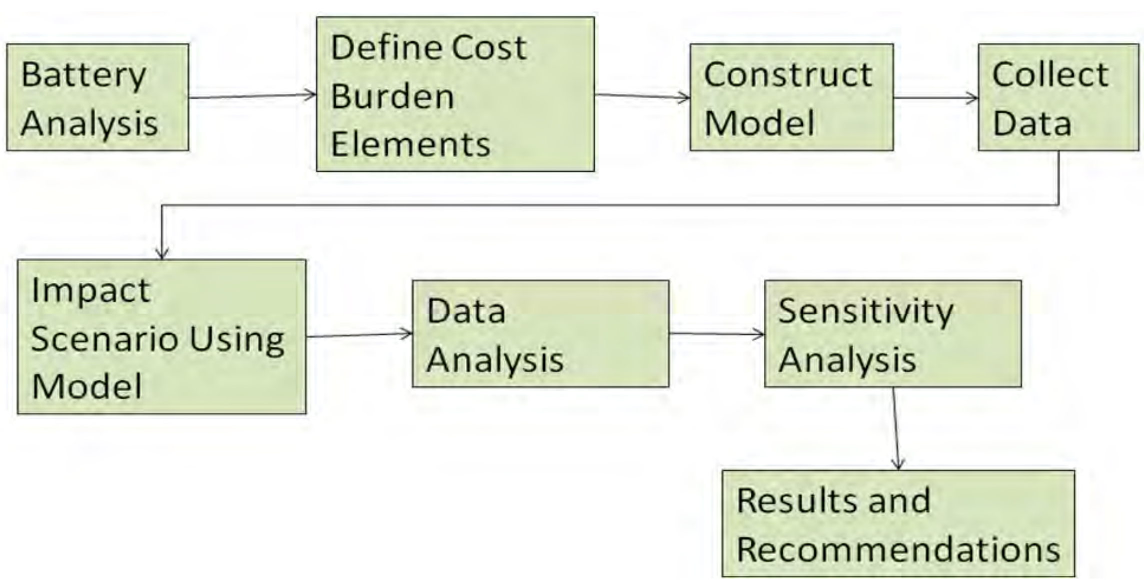

Figure 2. Impact of Rechargeable Battery Methodology

B. RESEARCH QUESTIONS

The primary objectives of this thesis are to develop a model for analyzing the IRB for use by decision makers and to do preliminary cost and weight computations for batteries required for a Marine Corps infantry battalion.

This thesis endeavors to answer the following secondary questions.

- What are the cost differences in purchasing, investment, and operations and maintenance (O&M), between current disposable BA-5590 batteries and the BB-2590 rechargeable batteries?
- What are other quantified benefits, such as transportation and disposal savings of using rechargeable batteries?
- Will rechargeable batteries lighten the load of a Marine Corps infantry battalion?

C. LIMITATIONS OF THE IMPACT OF RECHARGEABLE BATTERY COST ELEMENTS

The cost of using batteries depends on their operational use, so this thesis develops the IRB model that provides cost elements of using rechargeable batteries in varying scenarios. The results from the IRB should not be considered definitive, but rather useful for comparing the costs and benefits of the batteries and different systems used in the model. The results may aid decision-makers in their evaluation of short-term and long-term effects of employing non-rechargeable versus rechargeable batteries.

D. SCENARIO DEVELOPMENT

The author used the following operational scenario to compare the battery life cycle costs of disposable batteries with rechargeable batteries in the same system of principal end items (PEIs). The scenario uses basic requirements for a non-deployed Marine Corps infantry battalion conducting 30 days training operations in and around Marine Corps Base Twenty-nine Palms, California, for 30 days. Figure 3 outlines the life cycle flow chart of the batteries in this study.

The Table of Organization and Equipment (TO&E) detailed the number of radios that use XX90-series batteries. The author assumed 30 days of battalion fire and maneuver exercises. The battalion used AN/PRC-117F, AN/PRC-119F, and AN/PRC 150 radio systems. The other key assumptions are the following.

- The daily demand for XX90-series batteries is 182 per day. This assumption is based on information from an analysis by the Communication Officer's Course, Quantico, VA on the increased radio system densities for infantry battalion TO&E due to Operation Enduring Freedom and Operation Iraqi Freedom (MCCOC, 2010). POWER 1.3f was used to determine if rechargeable batteries could safely be used in each PEI. The BB-2590 batteries were used to their maximum capacity by monitoring the built in status of charge indicators (SOCI).
- Three DOS of rechargeable BB-2590 batteries and charging equipment replace 30 DOS of disposable BA-5590. This assumption is based on the charging capacity of 720 batteries per day of authorized charging systems. The 12 SPCs or 12 VMCs could satisfy the daily recharging requirement.
- The BB-2590 battery is engineered to be recharged between 224 and 1,000 times or more (M. Bissonnette, personal communication, May 2, 2011; Booz Allen Hamilton, 2003; Bren-Ttronics, personal communication, April 23, 2011).

Figure 3 outlines the CONUS scenario.

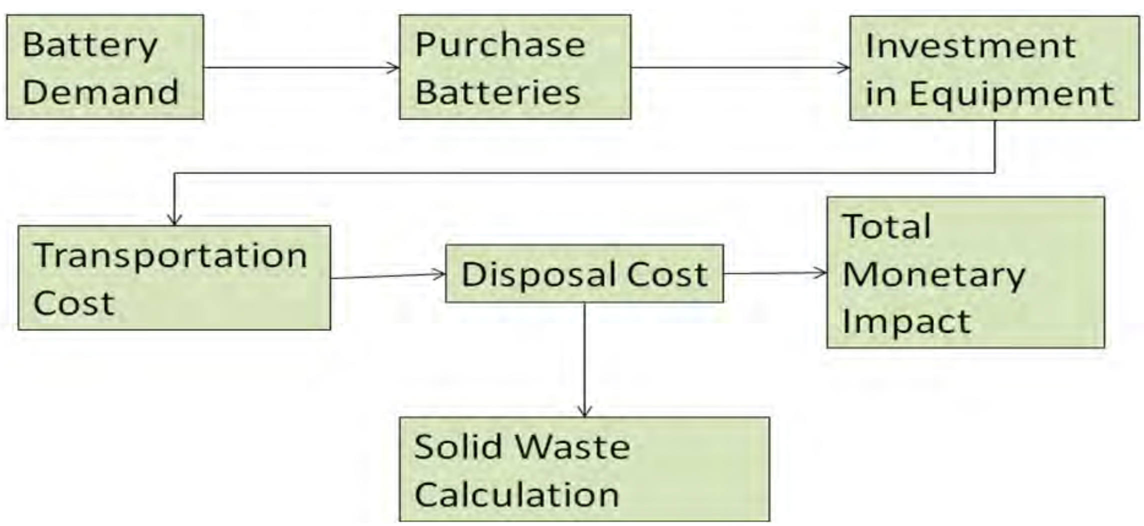

Figure 3. CONUS Scenario

E. RECHARGEABLE BATTERY COST ELEMENTS

Elements of the fully burdened cost of batteries (FBCB) model developed by Kiper et al. (2010) were utilized as a basis for quantifying the direct and indirect cost of rechargeable batteries. The cost drivers that apply to IRB are listed in Table 1.

Table 1. Battery Cost Elements

Battery Cost Burdens	
Cost Element Name	Description
Demand	Quantity of Batteries Required
Transportation	Cost of Ground Transportation From Defense Logistics Agency to Supply Management Unit
Investment	Total Cost of Required Recharging Equipment
Disposal	Cost per Pound of Solid Waste Disposal

Figure 4 illustrates how the sum of the cost drivers will be used to calculate the estimated total savings from using rechargeable batteries.

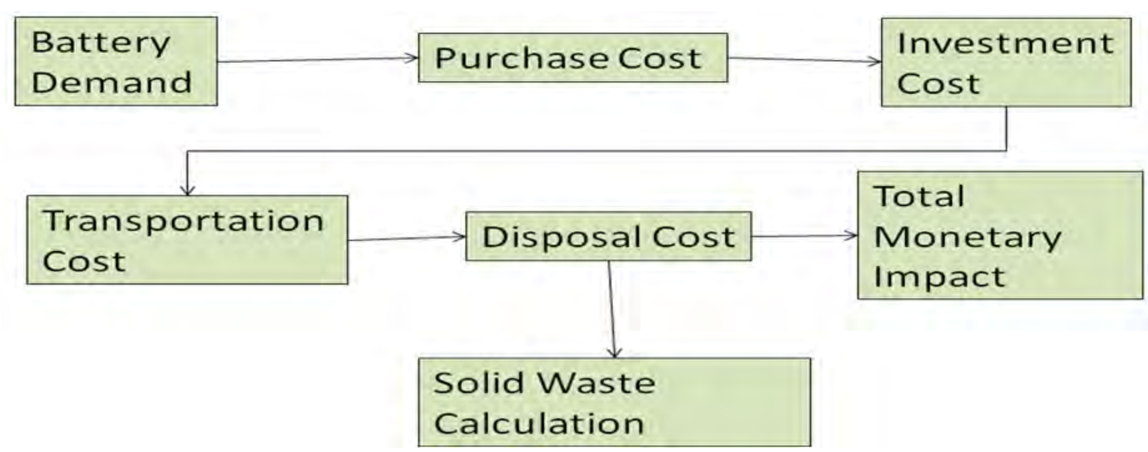

Figure 4. Life Cycle Flow Chart

The cost elements associated with batteries are based on the FBCB elements that were developed by Kiper et al. (2010). The cost burdens have been changed slightly to simplify the cost benefit analysis of the IRB. These changes are shown in Table 2. The FBCB used additional costs elements not related to the CONUS scenario of the IRB.

Additionally, the purchase price in the FBCB uses the manufacturer's government price whereas the IRB uses the DLA FY11 price. The cost elements used by the IRB include the following: purchase price, transportation cost, and disposal cost.

The IRB will show the estimated savings from using rechargeable batteries compared to the cost of using non-rechargeable batteries during each phase of the battery's life cycle. Table 2 shows the changes in costs.

Table 2. Comparison of FBCB and IRB Cost Elements

Cost Element Name	FBCB ($)	IRB ($)
Purchase Price	54.73	
BA-5590 Cost		76.68
BB-2590 Cost		289.00
Secondary Destination Transportation Costs	1.31	
Transportation Cost		1.81
Disposal Costs	1.28–2.25	
Disposal		1.28

1. Demand

The daily demand for batteries, also called days of supply (DOS), is the first input needed by the model. The number of batteries required is determined by the user given the situation, systems powered, duration, and the frequency with which a battery is replaced in each radio or weapon system. The IRB uses 182 batteries per day as the base case.

2. Purchase Costs and Savings

The purchase price of a battery is the amount paid by the battalion for each individual battery from DLA. Table 3 provides cost and weight data extracted from DLA, as recorded in POWER.

Table 3. Battery Purchase Price and Weights (From: Defense Logistics Agency, POWER 1.3f)

Battery Purchase Price		
	Unit Price	Unit Weight
BA-5590	$76.68*	2.25 lbs
BB-2590	$289.00*	3.2 lbs

The prices are the current FY2011 prices from DLA, which can be "an additional 45% over the original purchase price" (Kiper et al., 2010, p. 38) from the manufacturer. For the purposes of this thesis, the purchase price starts with the unit prices of $76.68 and $289.00 for the BA-5590 and BB-2590, respectively. These prices include the DLA cost burden identified by Kiper et al. (2010).

3. Purchase Savings

The purchase savings are outlined in the following equations:

$$\textit{Purchase Savings} = (n - 1) * \textit{Price of Disposable} - \textit{Price of Rechargeable}$$

where n = number of times the rechargeable battery is used.

For example, for n=1: *Purchase Savings*= (0 * $76.68) – $289= -$289.

That is, the first time a rechargeable battery was used there was no savings from the rechargeable battery to reduce the cost.

For n=2: (1 * $76.68) – 289 = -$212.32

For n=3: (2 * $76.68) – 289 = -$135.64

Table 4 shows the purchase savings for each recharge of a BB-2590. Note that there is a break-even point between four and five recharges.

Table 4. Purchase Savings

n= Uses	Reuses	BA-5590 Price ($)	BB2590 Price ($)	Savings ($)
1	0	76.68	289	-289.00
2	1	153.36	289	-212.32
3	2	230.04	289	-135.64
4	3	306.72	289	-58.96
5	4	383.40	289	17.72
6	5	460.08	289	94.40
7	6	536.76	289	171.08
8	7	613.44	289	247.76
9	8	690.12	289	324.44
10	9	766.80	289	401.12

4. Investment Costs

The IRB now considers the investment cost of purchasing the recharging equipment and will consider the cost of the batteries in a later section. The total cost to purchase recharging equipment is less than $112,887. There are currently three chargers authorized to recharge a BB-2590 battery (MCCOC, 2010): the Soldier Portable Charger (SPC), the Vehicle Mounted Charger (VMC), and the Solar Portable Alternative Communication Energy System (SPACES).

The SPC is a 27 lb. rugged suitcase that can charge multiple batteries of various sizes, voltage, and chemistry. The SPC can charge eight BB-2590s in eight hours or less (Appendix E) and costs $2,042 per unit (TO&E, 2011). The VCM is a 34 lb. charger that is mounted and wired into the electrical system of a tactical vehicle.

The VCM charges eight BB-2590s in five hours or less (see Appendix F) and can also charge multiple sizes, voltage, and chemistry batteries at the same time. A VCM costs $2,312 each (TO&E, 2011).

The SPACES charger is a flexible solar panel designed to be carried in a small patrol pack and weighs 2.6 lbs (see Appendix G), which is less than the weight of one rechargeable battery. It can charge two batteries while powering a radio in approximately

six hours and costs $5,053 per system (TO&E, 2011). A SPACES system can be “field stripped” to essential components, which weigh 1.2 lbs (MCCOC, 2010). Table 5 provides specifications for the three kinds of chargers.

Table 5. Recharging Systems

Chargers	Weight (lb.)	Unit Cost ($)	Fielding Plan per Battalion	Simultaneous Batteries Charged	Charge Time (hr)	Total Cost ($)	Max Recharge Capacity per Unit (24hr)	Subtotal Recharge Capacity (24hr)	Charger Weights (lb.)
SOLDIER PORTABLE CHARGER	27	2,042	12	8	8	24,504	24	288	324 #
SPACES	2.6	5,053	12	2	6	60,639	4 *	48	31.2
VEHICLE MOUNTED CHARGER	34	2,312	12	8	5	27,744	32 **	384	408 #
					Total Cost of Rechargers	112,887		720	763.2##
					Total BB-2590 Cost	157,794			
					Total Cost of Batteries with Rechargers	270,681			

Vehicle Carried;
Total Embarkation Weight;
* Assumes 12 Hours Daylight;
** Assumes 4 Complete Charge Cycles

A Marine Corps infantry battalion is authorized 12 of each recharging system (TO&E, 2011). The total cost of all 36 systems if purchased by the battalion is $112,887. However, the 36 initially fielded systems are a "free issue," to the battalion according to fielding plans (MCCOC, 2010), which means that the battalion does not spend its own Operation and Maintenance (O&M) funds to purchase the system.

The total weight for all 36 systems in the battalion is 763 lbs. The IRB considers the total weight for all batteries and charging systems that support the PEIs including the systems embarked for transportation, such as the VMCs and SPCs.

The maximum battalion recharging capacity for batteries is 720 per day (using all VMCs 24 hours and given 12 hours of daylight, which is not always possible). The 12 SPCs are capable of charging 288 batteries per day, which exceeds the estimated daily demand of 182.

The total investment cost is defined below.

Total Investment Cost = Total BB-2590 Cost + Total Cost of Rechargers

5. Transportation Costs and Savings

The transportation cost used for this model will be based on the secondary destination transportation charge (SDC) outlined in FBCB (Kiper et al., 2010, Table 11). Kiper et al. (2010) calculated the cost of transporting the battery from the DoD supply depot to the base/installation supply depot as $1.31 per pound and then converted this to a percentage of battery procurement costs. Specifically, they computed $1.31 / $54.73 = 2.39 percent. In the IRB calculation, this percentage is applied to the cost of a battery to get transportation costs as .0239 * $76.68 = $1.84 per lb.

6. Transportation Savings

The rechargeability of BB-2590 batteries provides the basis for estimating transportation savings when compared to the costs of transporting BA-5590 batteries, as shown in Table 6. The transportation savings equation is defined below:

*Transportation Savings = (n * Transportation Rate * Weight of Disposable) – (Transportation Rate * Weight of Rechargeable)*

where *n* = # times battery is used and *n*= 1,2, …,1000.

For example, for *n*=1:

Transportation Savings= (1 * \$1.31 * 2.25 lbs) – (\$1.84 * 3.2 lbs) = -\$2.94.

A rechargeable battery weighs .95 lbs more than a disposable. Because of rechargeability, a BB-2590 costs less to transport than numerous BA-5590 batteries.

For *n*=2: Transportation Savings (2 * \$1.31 * 2.25) – (\$1.84 * 3.2) = \$0.01

For *n*=3: Transportation Savings (3 * \$1.31 * 2.25) – (\$1.84 * 3.2) = \$2.95

Table 6. Transportation Savings

n=Uses	Transportation Rate (\$)	BA-5590 Weight (lb.)	BB-2590 Weight (lb.)	Transportation Savings (\$)
1	1.31	2.3	3.2	-2.94
2	1.31	4.5	3.2	0.01
3	1.31	6.8	3.2	2.95
4	1.31	9.0	3.2	5.90
5	1.31	11.3	3.2	8.85
6	1.31	13.5	3.2	11.80
7	1.31	15.8	3.2	14.74
8	1.31	18.0	3.2	17.69
9	1.31	20.3	3.2	20.64
10	1.31	22.5	3.2	23.59

7. Disposal Costs and Savings

Previous studies have estimated the average battery disposal cost per pound. As noted by Booz Allen Hamilton (2003), there are two methods for disposing of solid waste. The first method treats used batteries as hazardous material (HAZMAT) waste if there is a charge remaining. HAZMAT disposal is \$9.30 per battery (Ross & Hull, 1999) or \$4.04 per pound of BA-5590 $LiSO_2$ batteries.

The second method treats used batteries as nonhazardous solid waste (NHSW). According to Kiper et al. (2010), the disposal cost by the Department of Public Works Environmental Divisions at Joint Base Lewis-McCord, WA and Ft. Stewart, GA is $2.25 to $1.28 per pound, respectively.

The third option uses a commercial company, Toxco, at a rate of $2.5 to $3.5 per pound regardless of whether the batteries had a charge remaining at the time of disposal (Kiper et al., 2010). The differences among the disposal costs are mostly due to the location of the base and the distance to the disposal facility. For the purposes of the IRB, the lowest government provider cost of $1.28 per pound is used as the basis for the disposal cost because it was the most conservative government disposal estimate for NHSW and would not overestimate savings.

8. Solid Waste Calculation

In 2003, Booz Allen Hamilton wrote a report titled *Management Options for Used Lithium Sulfur Dioxide (*$LiSO_2$*) Primary Batteries* for the U.S. Army's concern over the growing amount of HAZMAT from $LiSO_2$ batteries (Booz Allen Hamilton, 2003). The Army leadership wanted to ensure compliance with the established environmental policies as the number of radios and used primary batteries increased significantly with the rapid buildup for Operation Iraqi Freedom. Booz Allen Hamilton reported that a complete discharge device (CDD) could be used to ensure no charge remained in an XX90-series battery. Accordingly, a properly discharged battery could be classified as NHSW instead of HAZMAT, saving money on disposal costs.

9. Disposal Savings

The rechargeability of BB-2590 batteries provides the basis for estimating disposal savings when compared to the costs of disposing BA-5590 batteries, as shown in Table 7. The NHSW disposal savings equation is defined below:

$$\textit{NHSW Savings} = (n * \textit{NHSW Cost} * \textit{Weight of Disposable}) - (\textit{NHSW Cost} * \textit{Weight of Rechargeable})$$

where n = # times battery used.

For example, for *n*=1: NHSW Savings n_1 = (1 * \$2.25 * 2.25 lbs) – (\$2.25 * 3.2 lbs) = -\$1.22.

That is, a rechargeable battery weighs .95 lbs more than disposable battery. On first use, a rechargeable battery costs more to dispose of compared to a disposable battery.

For *n*=2: NHSW Savings n_2 = (2 * \$2.25 * 2.25 lbs) – (\$2.25 * 3.2 lbs) = \$1.66

For *n*=3: NHSW Savings n_3 = (3 * \$2.25 * 2.25 lbs) – (\$2.25 * 3.2 lbs) = \$4.54

Table 7. NHSW Disposal Savings

n=Uses	Disposal Cost (\$)	BA-5590 Weight (lb.)	BB-2590 Weight (lb.)	Disposal Savings (\$)	NHSW Savings (lb.)
1	1.28	2.3	3.2	-1.22	-0.95
2	1.28	4.5	3.2	1.66	5.80
3	1.28	6.8	3.2	4.54	17.05
4	1.28	9.0	3.2	7.42	32.80
5	1.28	11.3	3.2	10.30	53.05
6	1.28	13.5	3.2	13.18	77.80
7	1.28	15.8	3.2	16.06	107.05
8	1.28	18.0	3.2	18.94	140.80
9	1.28	20.3	3.2	21.82	179.05
10	1.28	22.5	3.2	24.70	221.80

10. Solid Waste Savings

Each recharge of a BB-2590 battery results in physically fewer batteries accumulating in the landfill, compared to disposable BA-5590 batteries discarded after one use. Each subsequent use of a BB-2590 saves 2.25 pounds of $LiSO_2$ NHSW from going into a landfill, as shown in Table 8.

The solid waste savings calculation is described by:

Pounds of Solid Waste Savings = (n * Weight of Disposable) – (Weight of Rechargeable)

where n = # times battery used.

For example, for n=1: NHSW Savings= (1 * 2.25 lbs) – (3.2 lbs) = -.95 lb.

That is, a rechargeable battery weighs .95 lbs more than a disposable battery. On first disposal a rechargeable battery costs more to dispose of compared to a disposable battery.

For n=2: NHSW Savings= (2 * 2.25 lbs) – (3.2 lbs) = 1.3 lbs

For n=3: NHSW Savings= (3 * 2.25 lbs) – (3.2 lbs) = 3.6 lbs

11. Disposal Cost Savings

When the estimates done in the previous paragraphs are combined, as pounds of solid waste are reduced, the disposal costs of the NHSW are similarly reduced. Table 8 shows the disposal savings per battery.

Table 8. Disposal Savings

n=Uses	NHSW Disposal Cost ($)	BA-5590 Weight (lb.)	BB-2590 Weight (lb.)	Disposal Savings ($)
1	1.28	2.3	3.2	-1.22
2	1.28	4.5	3.2	3.33
3	1.28	6.8	3.2	13.63
4	1.28	9.0	3.2	29.70
5	1.28	11.3	3.2	51.52
6	1.28	13.5	3.2	79.10
7	1.28	15.8	3.2	112.45
8	1.28	18.0	3.2	151.55
9	1.28	20.3	3.2	196.42
10	1.28	22.5	3.2	247.04

12. Weight Savings-Less Equipment Carried

The previous paragraphs address financial savings from using rechargeable batteries. This paragraph addresses possibility of carrying less equipment to conduct operations. Table 9 shows the costs and weights of 30 DOS of BA-5590 and BB-2590. Both weight savings and percent savings are calculated and displayed in Table 9.

Table 9. Weight Saving of BB-2590 Compared to BA-5590 Batteries

BA-5590				BB-2590			Savings	
DOS	BA-5590B/U Qty (ea)	BA-5590 Cost ($)	BA-5590 Weight (lb)	BB-2590/U Qty (ea)	BB-2590 Cost Batts & Chrgrs ($)	BB-2590 Weight Batts &Chrgrs (lb)	Weight Savings (lb)	Weight Savings (%)
1	182	13,989	410	182	165,485	1,346	(936)	329%
2	364	27,977	819	364	218,083	1,928	(1,109)	235%
3	546	41,966	1,229	546	270,681	2,510	(1,282)	204%
4	728	55,954	1,638	546	270,681	2,510	(872)	153%
5	910	69,943	2,048	546	270,681	2,510	(463)	123%
6	1,092	83,931	2,457	546	270,681	2,510	(53)	102%
7	1,274	97,920	2,867	546	270,681	2,510	356	88%
8	1,456	111,908	3,276	546	270,681	2,510	766	77%
9	1,638	125,897	3,686	546	270,681	2,510	1,175	68%
10	1,820	139,885	4,095	546	270,681	2,510	1,585	61%
15	2,730	209,828	6,143	546	270,681	2,510	3,632	41%
20	3,640	279,770	8,190	546	270,681	2,510	5,680	31%
25	4,550	349,713	10,238	546	270,681	2,510	7,727	25%
30	5,460	419,656	12,285	546	270,681	2,510	9,775	20%

13. Total Monetary Savings

Table 10 tabulates the total monetary savings as a function of n, the number of recharges. The total monetary savings for each BB-2590 is calculated as follows.

Total Monetary Savings = Purchase Savings + Transportation Savings + NHSW Disposal Savings

Table 10. Total Monetary Savings

n= Times Battery Used	Purchase Savings ($)	Transportation Savings ($)	NHSW Disposal Savings ($)	Total Monetary Savings ($)
1	-289.00	-1.75	-1.22	-291.96
2	-212.32	2.39	1.66	-208.26
3	-135.64	6.53	4.54	-124.56
4	-58.96	10.67	7.42	-40.86
5	17.72	14.81	10.30	42.84
6	94.40	18.95	13.18	126.54
7	171.08	23.09	16.06	210.24
8	247.76	27.23	18.94	293.94
9	324.44	31.37	21.82	377.64
10	401.12	35.51	24.70	461.34

14. Fully Burdened Cost of Rechargeable Batteries

As an extension of previous studies, adding the direct and indirect life cycle costs will estimate the fully burdened cost (FBC). The additional transportation or operations and support (O&S) and disposal costs need to be considered singularly, categorically, as a percentage, and as a total outlined in Table 11.

The FBC is defined as the following.

Fully Burdened Cost (FCB) Total Cost = Purchase Price + Transportation Cost + NHSW Disposal Cost

Table 11. FBC Costs

Battery	Purchase Price ($)	Transportation Cost ($)	Disposal Cost ($)	FBC Total Cost ($)	Difference %
BA-5590	76.68	2.95	2.88	82.51	8%
BB-2590	289.00	6.11	4.10	299.20	4%

15. Return on Investment

To determine the return on investment (ROI) as used throughout the business and investment industry, take the value from the total monetary savings per battery multiplied by the daily requirement, and then divide by the total investment cost that includes all batteries and equipment. That is:

ROI = (Total Monetary Savings per Battery * Daily Requirement) / (Total Investment Cost)

ROI = (Total Monetary Savings per Battery * 182) / (270,681 – (182 * n* 76.68)).

Table 12 demonstrates the increasing ROI during a month of operations, for various number of recharge cycles.

Table 12. Return on Investment per Battery Using FBC

Times Battery Used	Purchase Savings ($)	Transportation Savings ($)	NHSW Disposal Savings ($)	NHSW Disposal Savings (lb)	Total Monetary Savings ($)	ROI of 182 Batt/Day
1	-299.2	-1.7	-1.2	-1.0	-302.1	-34%
2	-216.4	2.4	1.7	1.3	-216.5	-18%
3	-133.9	6.5	4.5	3.6	-122.8	-8%
4	-51.4	10.7	7.4	5.8	-33.3	-2%
5	31.1	14.8	10.3	8.1	56.3	4%
6	113.7	19.0	13.2	10.3	145.8	10%
7	196.2	23.1	16.1	12.6	235.3	16%
8	278.7	27.2	18.9	14.8	324.8	22%
9	361.2	31.4	21.8	17.1	414.4	28%
10	443.7	35.5	24.7	19.3	503.9	34%

Figure 5 shows the return on investment (ROI) from using rechargeable batteries.

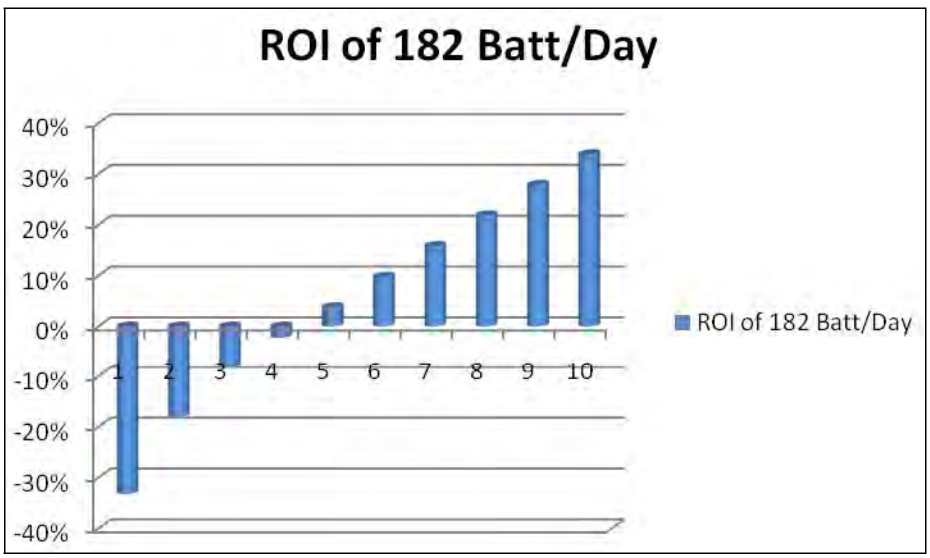

Figure 5. Return on Investment of 182 Batteries per Day

16. Sensitivity Analysis

Key variables in the ROI analysis are the following.

- Battery demand per day
- Number of times the each rechargeable battery is recharged

To determine the sensitivity of the IRB model to these variables, the author created a sensitivity matrix that estimates the saving from batteries needed (1 to 1000) and the number of times each battery was recharged (1 to 1000). One can systematically change a parameter in the model to determine the effects on savings, or one can look up the number of batteries needed per day and the number of times a battery would be recharged.

Using the FBC multiplied times the daily demand times the number of times used minus the FBC of required BA-5590s generates a range of potential savings. The sensitivity analysis allows decision-makers to better estimate whether using rechargeable batteries offers compelling value and thereby permit quick decision making. The results are calculated on Table 13.

Table 13. Sensitivity Extract

Batts/Day	Number of Times Recharged ($FBC) 1	5	10	50	100	150	200	224	300	500	1000
1	(292)	44	463	3,818	8,012	12,206	16,400	18,413	24,788	41,564	83,504
45	(13,138)	1,960	20,833	171,817	360,547	549,277	738,007	828,597	1,115,467	1,870,387	3,757,687
91	(26,569)	3,964	42,129	347,452	729,106	1,110,760	1,492,414	1,675,608	2,255,722	3,782,338	7,598,878
182	(53,137)	7,927	84,258	694,904	1,458,212	2,221,520	2,984,828	3,351,216	4,511,444	7,564,676	15,197,756
364	(106,275)	15,854	168,516	1,389,809	2,916,425	4,443,041	5,969,657	6,702,432	9,022,889	15,129,353	30,395,513
728	(212,550)	31,709	337,032	2,779,618	5,832,850	8,886,082	11,939,314	13,404,865	18,045,778	30,258,706	60,791,026

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IV. ANALYSIS

A. WEIGHT ANALYSIS

Rechargeable BB-2590 batteries weigh more than disposable BA-5590 batteries, and additional charging equipment is required when using rechargeable batteries. However, fewer rechargeable batteries are need for prolonged operations; the net result is a total weight savings. Figure 6 shows that three DOS of BB-2590 weigh less than seven DOS of BA-5590s. Additionally, three DOS of BB-2590 with all charging equipment weigh 80% less than 30 DOS of disposable batteries, as seen in Table 9 and Appendix H.

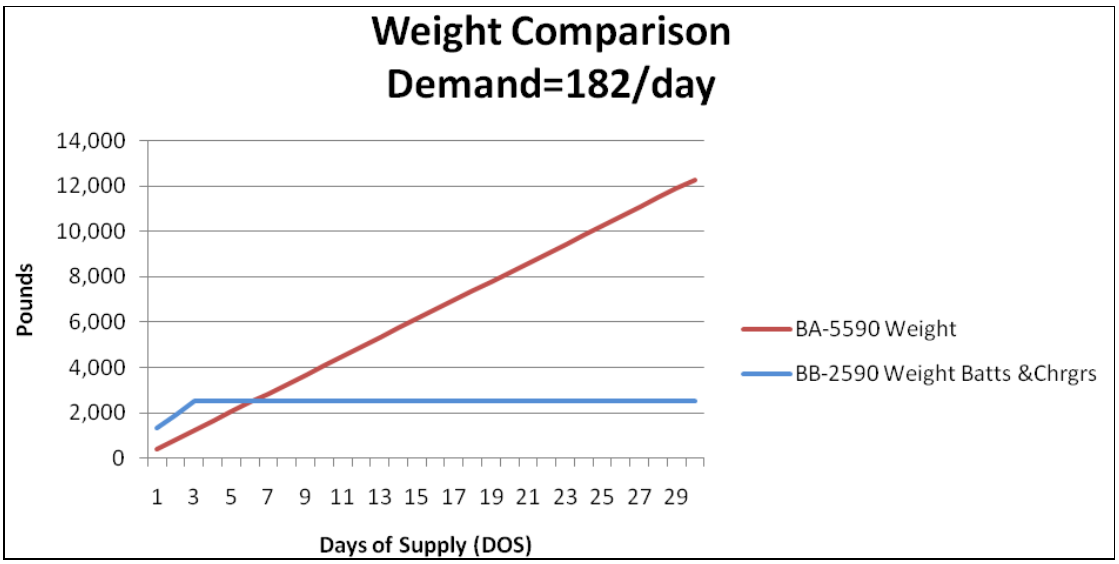

Figure 6. Weight Comparison

As demonstrated in Chapter IV, net weight savings are a significant factor because weight is also a cost driver. As the daily demand for batteries increases, the net weight savings from rechargeable batteries become more advantageous. The additional weight of the charging equipment varies from 12 lbs to 763 lbs. The SPCs and VMCs are transported by vehicles. Again, the IRB uses the aggregated weight for all rechargeable batteries and recharging systems that an infantry battalion owns.

B. COST ANALYSIS

Similar to the weight analysis, the investment in BB-2590 batteries and charging equipment is greater than the cost of using BA-5590 batteries. A cost breakeven point is seen at the 20-day mark (Appendix H). The cost of $279,770 for disposable batteries is greater than the cost of $270,681 for rechargeable batteries and all charging equipment. Figure 7 shows the simple purchase cost comparison between BA-5590 batteries and BB-2590 batteries with all charging equipment, as a function of DOS.

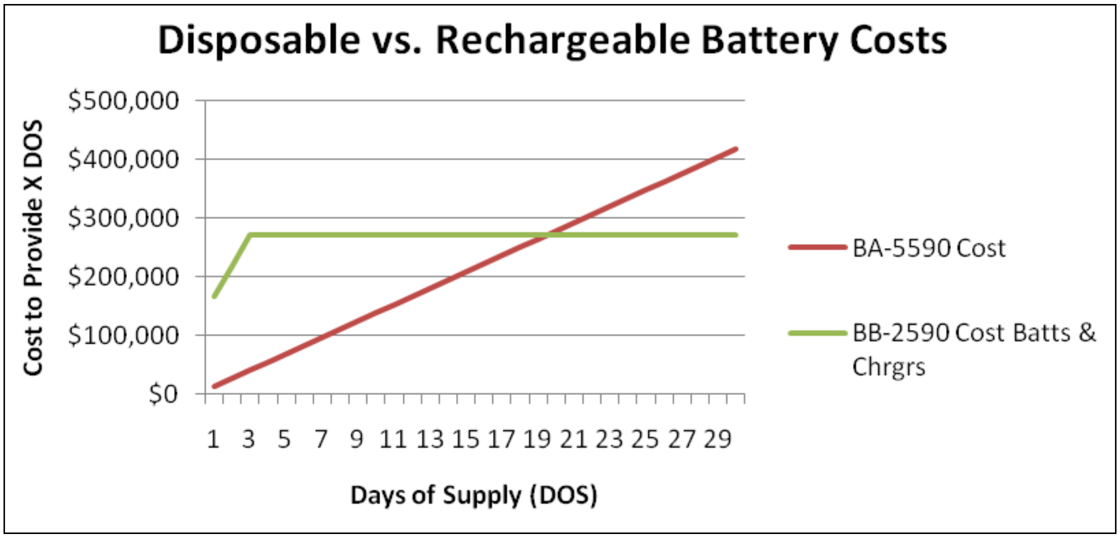

Figure 7. Cost Comparison

C. FULLY BURDENED COST ELEMENTS

As fully burdened cost (FBC) elements are included in the analysis, the cost breakeven point between BA-5590s and BB-2590s decreases. By including the FBC elements, the breakeven point shifted to the left by one day (Appendix H). Figure 8 shows the difference between the FBC costs compared to the simple purchase cost functions.

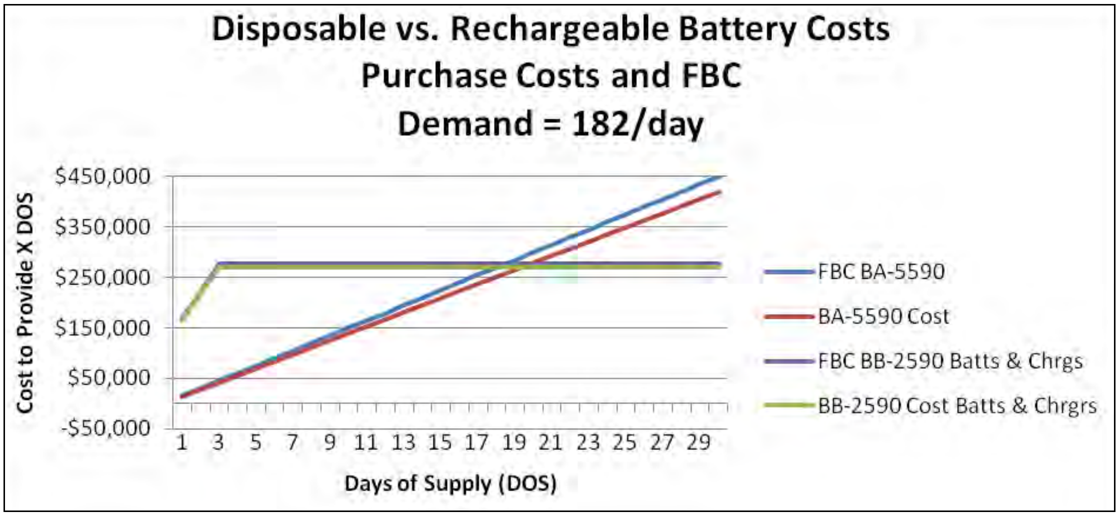

Figure 8. Cost Comparisons of Fully Burdened Cost Elements

As the daily demand for batteries increases, the FBC breakeven point continues to shift to the left. Figure 9 shows the relationship between the varying daily demands. The FBC breakeven points using various daily demands of 91, 182, and 364 are 26, 19, and 15 days, respectively. The conclusion is that, when demand increases, the savings from using rechargeable batteries becomes more favorable.

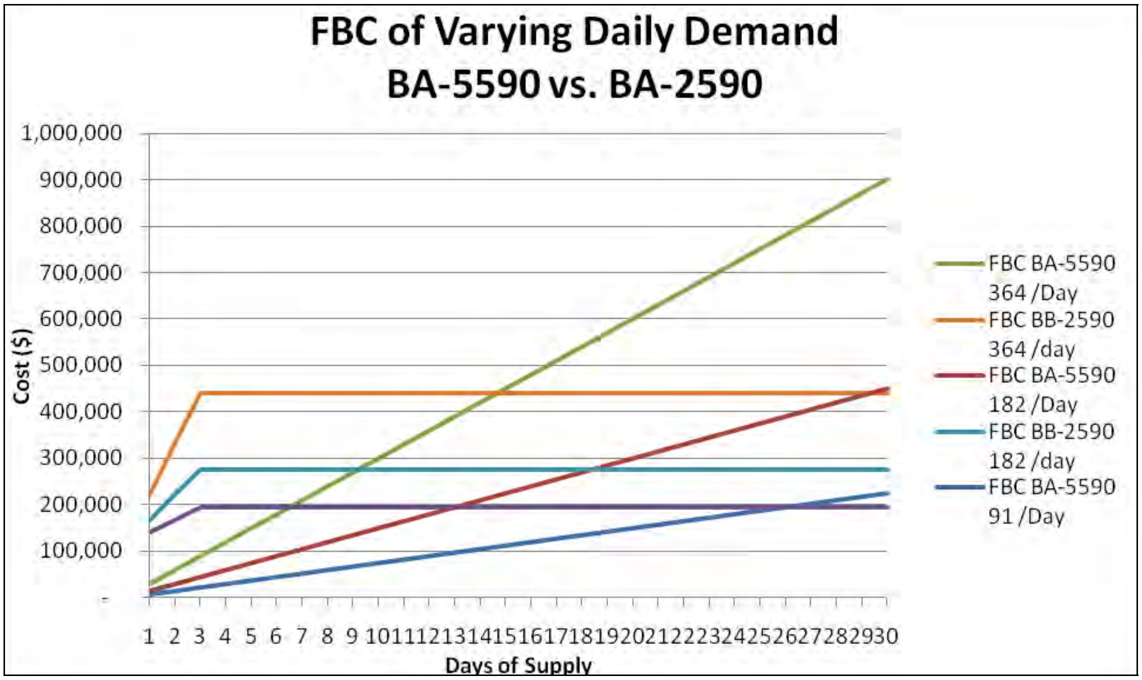

Figure 9. FBC Comparison Between Various Daily Demands

Figure 10 shows the accumulation of savings of each life cycle cost.

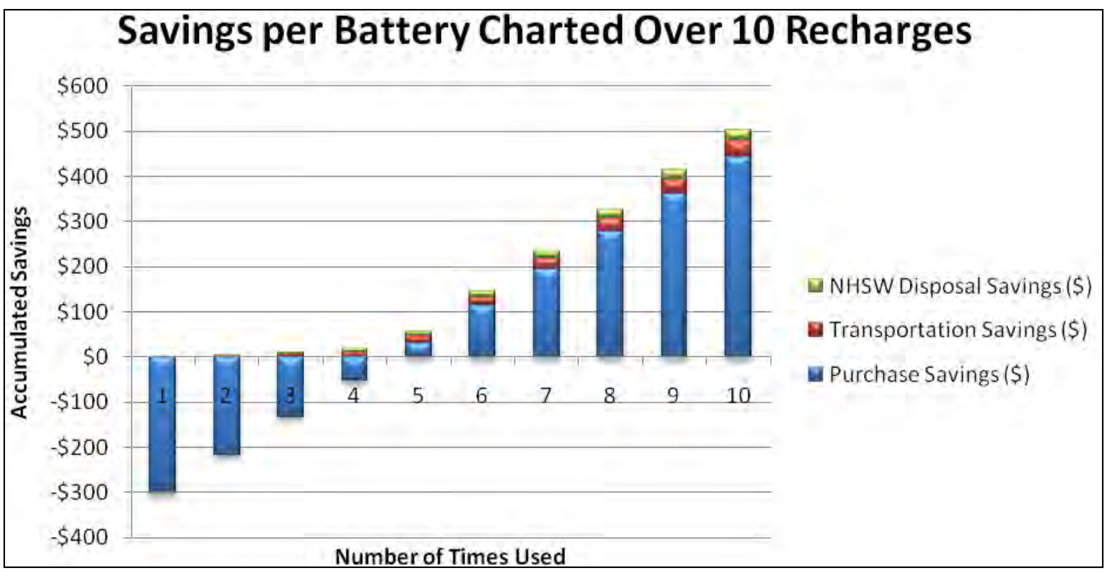

Figure 10. Savings from Rechargeable Batteries Over 10 Uses

As each cost element increases, the savings from using rechargeable batteries increases. The savings are compounded with each use of a rechargeable battery.

In the 30-day scenario, each BB-2590 would be recharged 10 times. The FBC elements as a percentage of purchase price is essentially compounded each time the rechargeable battery is re-used. For example, Figure 11 displays the cost burdens as a percentage of the purchase price and total dollars saved if a single battery were used 1,000 times.

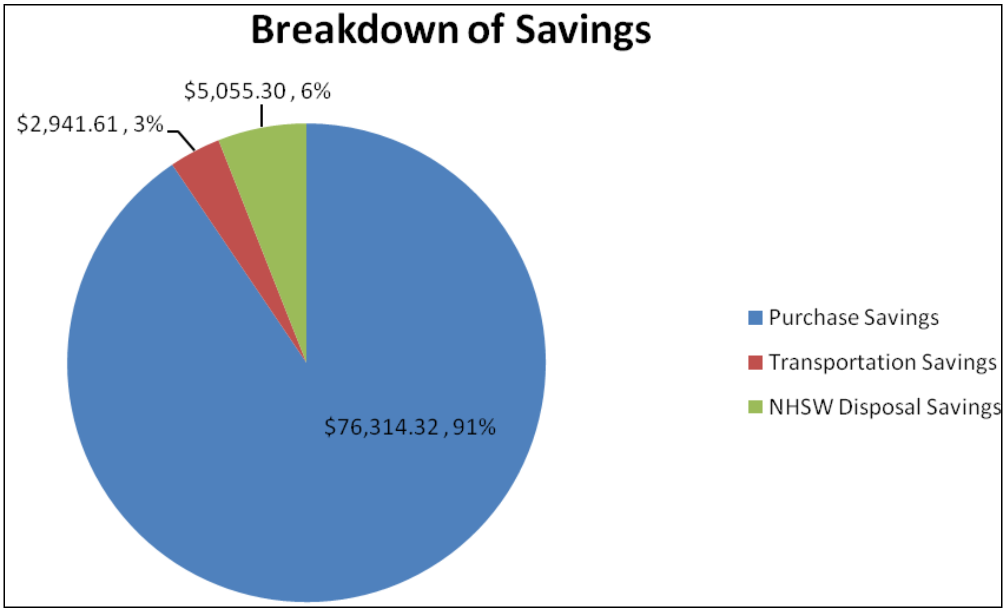

Figure 11. Breakdown of Savings by Percentage

Figure 12 portrays the breakdown of cumulative savings as a rechargeable battery is recharged again and again—up to 1,000 times.

Figure 12. Accumulation of Savings

D. SOLID WASTE SAVINGS

Each time a rechargeable battery is used, it saves another battery from being discarded into a landfill or being sent to a disposal service shown in Table 9. Therefore, rechargeable batteries can provide solid waste disposal savings, and these savings can be estimated from the weight of the batteries. For example, 182 rechargeable batteries used 10 times prevents 3,512 lbs and 1,665 cubic feet of $LiSO_2$ waste from entering a landfill after a 30 day operation. Additionally, there is a reduction in environmental risk, although the value of this reduction is yet to be determined. Figure 13 shows the accumulated weight saving throughout the life cycle of a BB-2590.

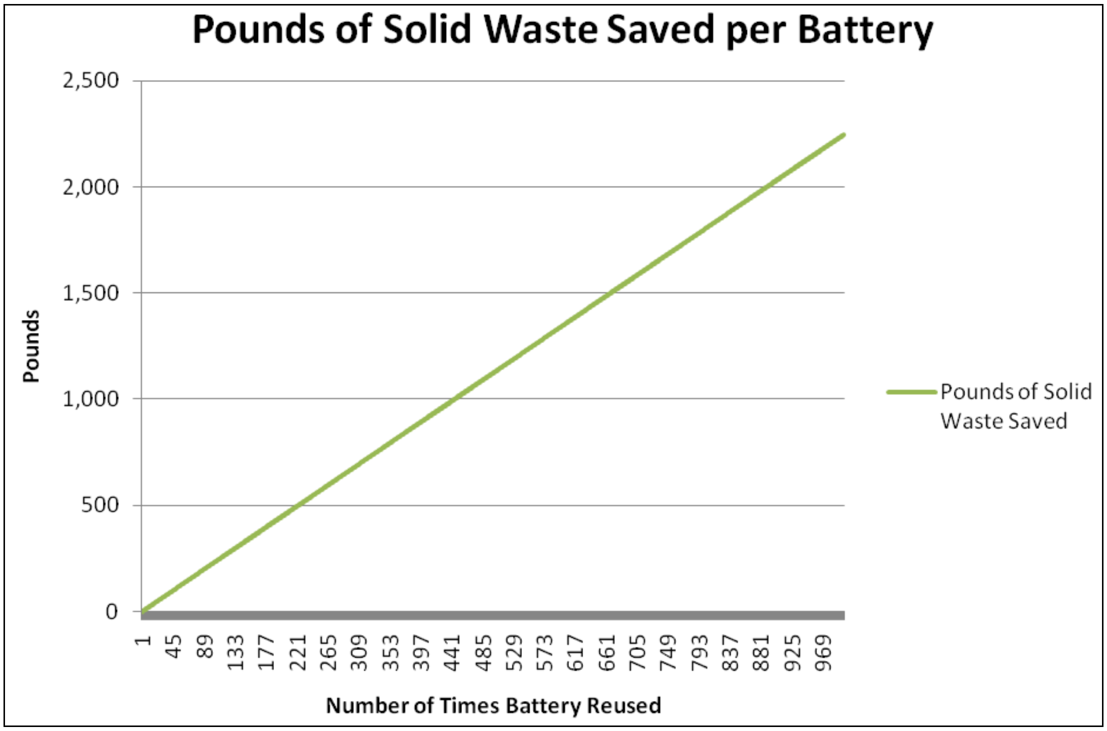

Figure 13. Solid Waste Savings per BB-2590 Battery

E. SENSITIVITY ANALYSIS

Sensitivity analysis demonstrates the robustness of the analysis. It illustrates the changes in savings as the daily demand and usage changes. Table 14 is an extract from the sensitivity analysis table. Table 14 shows the range of savings depending on the number of batteries required per day and the number of times each battery is recharged. For example, 182 batteries used 100 times would save an estimated $1,458,212.

Table 14. Sensitivity Extract

	Number of Times Recharged ($FBC)										
Batts/Day	1	5	10	50	100	150	200	224	300	500	1000
1	(292)	44	463	3,818	8,012	12,206	16,400	18,413	24,788	41,564	83,504
45	(13,138)	1,960	20,833	171,817	360,547	549,277	738,007	828,597	1,115,467	1,870,387	3,757,687
91	(26,569)	3,964	42,129	347,452	729,106	1,110,760	1,492,414	1,675,608	2,255,722	3,782,338	7,598,878
182	(53,137)	7,927	84,258	694,904	1,458,212	2,221,520	2,984,828	3,351,216	4,511,444	7,564,676	15,197,756
364	(106,275)	15,854	168,516	1,389,809	2,916,425	4,443,041	5,969,657	6,702,432	9,022,889	15,129,353	30,395,513
728	(212,550)	31,709	337,032	2,779,618	5,832,850	8,886,082	11,939,314	13,404,865	18,045,778	30,258,706	60,791,026

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

The model shows that the greater the daily demand for batteries, the greater the savings from using rechargeable batteries. Figure 10 demonstrates that as each cost burden (i.e., transportation or disposal cost) increases, the savings from rechargeable batteries increases. As daily demand increases, breakeven points are experienced sooner as shown in Figure 9. Furthermore, the savings are compounded each time the battery is recharged. Figure 14 demonstrates the 34% ROI in the scenario from using three DOS of rechargeable batteries charted over the first ten uses.

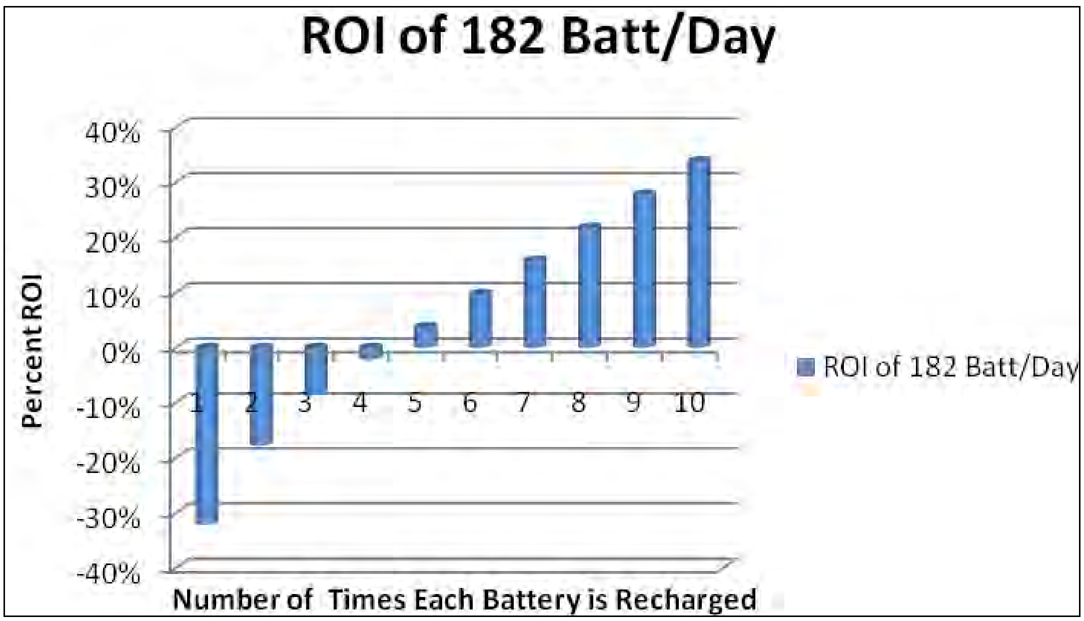

Figure 14. Return on Investment from Rechargeable Batteries

Figure 15 shows the ROI increasing as a function of the number of times a rechargeable battery is reused based on a 182 batteries per day requirement.

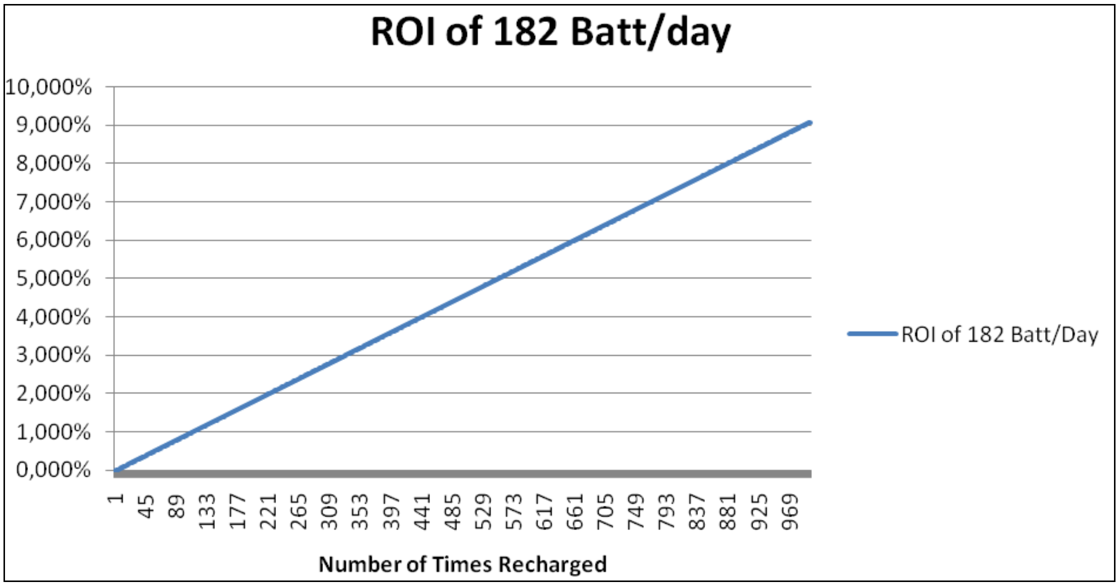

Figure 15. Return on Investment of 182 Batteries per Day

Appendix H lists the daily IRB scenario calculations. Table 14 estimates the range of savings determined by the daily demand and number of times each battery is recharged.

Rechargeable batteries have reduced life cycle costs, which generate savings by replacing recurring costs with a single purchase, transportation, and disposal cost. Most of the savings from rechargeable batteries will be experienced by the using battalion. Transportation and disposal savings will be experienced by supporting units and base organizations.

A battalion that uses rechargeable batteries would not need be resupplied with batteries by an external supporting unit. According to Hargeaves (2011), one in eight Army casualties resulted from protecting convoys. A logical extension is that by using rechargeable batteries at forward combat outposts and operating bases, resources would be reduced or eliminated from resupply convoys. The risk reduction and associated savings are outside the scope of this thesis.

Using rechargeable batteries is one step among many that can be taken now that will save money, reduce weight, save lives, and reduce resource consumption. Rechargeable batteries will increase energy independence and reduce DoD resource vulnerability, risk of uncertainty, and future costs and budgets.

B. RECOMMENDATIONS FOR FURTHER STUDY

1. Develop Rechargeable Battery Technology

Manufacture lighter rechargeable batteries to reduce weight on the warfighter. Increased power density and longer lasting batteries means fewer batteries are required.

2. Battery Commonality

Ensure new electronics can use existing rechargeable batteries. Adapters should be developed so multiple devices can be powered by a single rechargeable battery when worn.

3. Risk Reduction and Savings from Reduced Convoys

Develop a model that would estimate the risk reduction and savings from fewer resupply convoys due to energy independence.

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APPENDIX A. MANUFACTURER'S DATA ON THE BA-5590

BA 5590

Lithium / Sulfur Dioxide Primary Battery System

Physical Specifications:

Typical Weight:	2.25 lbs; 1000 gr.
Weight of Li:	24 gr.
Dimensions:	Figure A (on back)
Battery Case:	Plastic

Typical Applications:

AN / PRC-104	Radio
AN / PRC-113	Radio
AN / PRC-117	Radio
AN / PRC-119	Singcars Radio
KY-57, KY-65	Encryption Set
REMBASS	Remotely Monitored Battlefield Surveillance System
PLRS	Position Locator and Reporting System
RT-991	Buoy Radio
RT-1175	Buoy Radio
AN / TAS-4A	TOW Night Sight

Electrical Characteristics:

Construction:	10 LO 26 SX cells connected in 2 groups of 5 cells in series providing 2 nominal 12-volt sections at connector. These sections can be connected in series (for 24 volts) in parallel (for 12 volts) or used as two separate 12-volt units
Voltage:	Typical OCV: 15.0 or 30.0 volts Nominal (@500 ma): 13.5 or 27.0 volts Cut-off: 10.0 or 20.0 volts
Typical Capacity: @70°F (21°C) (@ 250 mA discharge current):	12 volts mode 15 Ah / 24 volts mode 7.5 Ah
Operating Temperature:	-40°F to 160°F (-40°C to 71°C)
Storage:	Recommended max 95°F (35°C) / Possible -40°F to 160°F (-40°C to 71°C)
Fuse:	Non-replaceable, electrical fuse is incorporated in the negative leg of each series group of cells.
High Temperature Switch:	A normally closed high temperature switch or thermal fuse is incorporated into each series leg of cells to protect against overheating
Diode:	A diode is incorporated into the positive leg of each series group of cells to prevent charging or flow of current into the battery
Pull tab CDD (optional):	A device consisting of a manually activated pull tab and resistors designed to discharge the battery to 0 volts is built into the battery
Mating Connector:	ITT Cannon CA 110821-6
Reference Specifications:	MIL PRF 49471B or Saft Standard Specification

The BA 5590 is a commonly used battery for various military applications.

saft

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APPENDIX B. MANUFACTURER'S DATA ON THE BB-2590/U

Bren-Tronics, Inc.
"Military Batteries & Charging Systems"

Battery

BB-2590/U

Rechargeable, Lithium-Ion Battery

Product Note:
This product complies with SMBus v1.1, SBData v1.1
Part of the **'Intelligent Battery System'** ®
The only BB-2590/U Certified for Military Use
Total Energy of 207 Wh

Typically Used in:
- SINCGARS & ATCS (AN/PRC-104, 117, 119)
- FALCON (AN/PRC-138, 117) KY-57
- MXF430 (V), AN/PSC-5, M22

Replacement for or Compatible with:
BB-2590/U (BT-70791E)
BB-390B/U (BT-70790)
BB-390A/U (BT-70290)
BB-590/U (BT-70409)
BB-490/U
BB-690/U
BA-5590/U
BA-3590/U

Recommended Charger	Required Adapter
BTC-70801	BTA-70834
BTC-70644	BTA-70834
BTC-70819	BTA-70834
BTC-70836	BTA-70841
	BTA-70820
BTC-70870,-"X"	BTA-70841
	BTA-70820
BTC-70824-2	N/A
BTC-70791-LR	N/A
BTC-70791-MR	N/A
BTC-70822-MR	N/A
BTC-70824-1	BTA-70762
BTC-70663	BTA-70762

When Ordering Specify P/N:
BT-70791A

Technical Data	
National Stock Number	6140-01-490-4316
BT Part No.	BT-70791A
Dimensions	**Length:** 4.4 in (112 mm) **Width:** 2.4 in (61 mm) **Height:** 5.0 in (127 mm)
Weight	3.1 Lb (1.4 Kg)
Voltage (Nominal)	28.8V, Two (2) x 14.4V/Section
Voltage (Maximum)	33.0V, Two (2) x 16.5V/Section
Capacity	6.8 Ah in 24V Mode; 13.6 Ah in 12V Mode
Discharge	10A max. Continuous / Section
Pulse Discharge	18A (5 sec ON / 25 sec OFF) / Section
Operating Temperature	-20°C to +55°C (-4°F to +131°F)
Storage Temperature	-40°C To +40°C (-40°F To +104°F)
Connector	Floating type per U.S. Army DWG # SC-C-179495
State of Charge Display	2 Separate 5 Segment LCD's with Constant Display
Disposal	Environmentally Safe - See Material Safety Data Sheet (MSDS)

For a complete description of our products refer to Bren-Tronics website at: http://www.bren-tronics.com

10 Brayton Court, Commack, NY 11725 Tel 631.499.5155 Fax 631.499.5504
Email sales@bren-tronics.com www.bren-tronics.com

DS BT-7079

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APPENDIX C. MANUFACTURER'S DATA ON THE BB-390/U

BB-390/U Battery

Nickel Metal Hydride

- High performance rechargeable nickel metal hydride battery.
- Durable high impact plastic housing and connector enclosure
- High reliability due to all welded construction
- Unit contains safety vented cells

This battery is engineered and designed for use in a world wide tactical environment, and is manufactured to meet and exceed US MIL-SPEC and ISO9000 methods and procedures. This battery meets the requirements of MIL-PRF-32052 with reference to MIL-STD-810 for:

Battery voltage	Electrolyte leakage	Vibration
Mechanical and thermal shock	Insulation resistance	

For use in	PRC-104, PRC-119, PRC-138, KY-57 and other equipment
Replacement for	BB-390A/U, BA-3590/U, BA-5590/U, BB-490/U, BB-590/U
Cell chemistry	Nickel Metal Hydride
Nominal voltage	24 Volts or two 12V sections depending on connection
Typical capacity	3.6Ah @ 24V, 7.2Ah @ 12V (minimum)
Nominal dimensions	112 x 63 x 127 mm
Nominal weight	1.76kg
Connector	Floating type, to SC-C-179495
Venting	Battery has pressure release valve
Case material	Modified ABS plastic olive drab
Operating temperature	-20°C to +55°C
Storage temperature	-40°C to +55°C
Shelf life	Up to 5 years depending upon storage conditions
Disposal	Battery must be recycled

Mathews Associates, Inc.
220 Power Court
Sanford FL 32771
Phone: (407) 323-3390 Fax: (407) 323-3115
Email: sales@maifl.com

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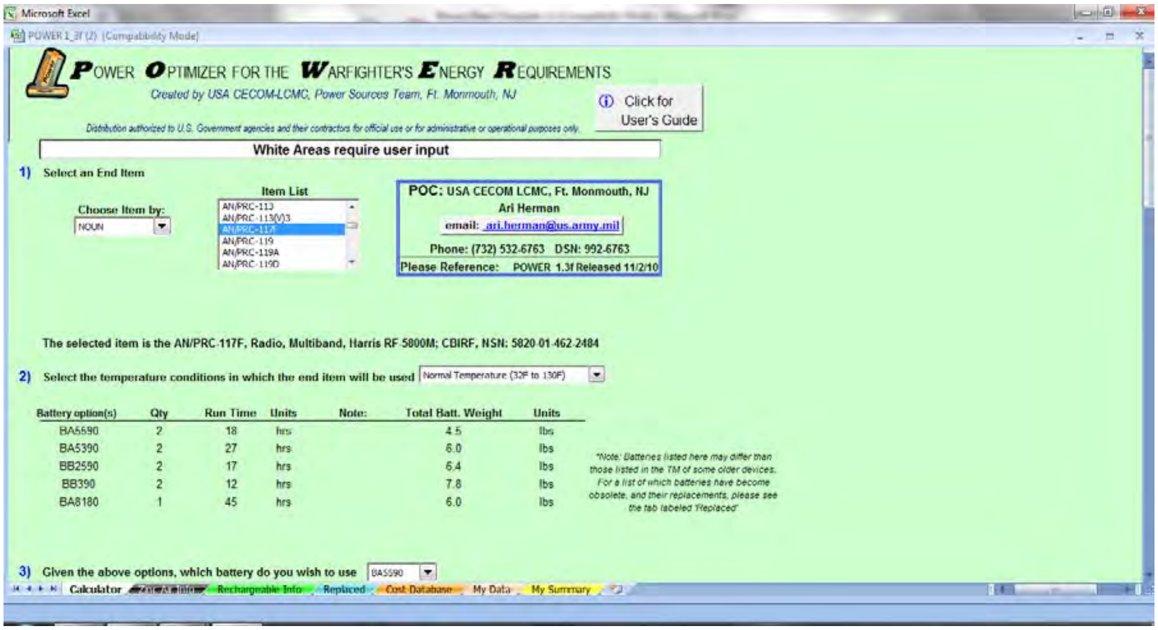
APPENDIX D. POWER VERSION 1.3F



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APPENDIX E. MANUFACTURER'S DATA ON THE SUITCASE PORTABLE CHARGER

BATTERY CHARGER, SUITCASE PORTABLE CHARGER (SPC)

NSN: 6130-01-495-2839	TAMCN: A0012	ID: 11099A

Functional Description

The Suitcase/Soldier Portable Charger (SPC), (PP-8498/U) is a dual-channel sequential charger that automatically charges up to eight batteries (two at a time) in approximately eight hours depending on battery type and state-of-charge. The SPC comes with (4) J-6358B/P (BB-2590/U – BB-390B/U) adapters. All other adapters are ordered separately. The SPC can hold up to four adapters (one per port) and each adapter holds two batteries. The SPC operates from AC or DC power. For vehicle supplied DC power the SPC has a low voltage cutoff to avoid draining the vehicle battery.

Technical Description

Battery Charger		**Dimensions**	
Manufacturer:	Bren-Tronics	Length (in):	22.8
Model:	PP-8498/U	Width (in):	14.6
Input:	90 to 260 VAC or 22-28 VDC	Height (in):	9
		Weight (lb):	27.5
Frequency (Hz):	47-420	Volume (ft^3):	1.8
Warranty:	4 years from MFG date		

Adapter	Adapter NSN	Battery	Battery
J-6358B/P	5940-01-501-3312	BB-2590/U	BB-390B/U
J-6357A/P	5940-01-493-6388	BB-388A/U	BB-388/U
J-6356/P	5940-01-427-9183	BB-326/U	BB-516A/U
J-6355/P	5940-01-427-9247	BB-503A/U	
J-6354/P	5940-01-427-9278	BB-2847A/U	BB-2847/U
J-6523A/P	5940-01-492-7238	BB-557/U	BB-2557
J-6521/P	5940-01-467-8813	BB-2600A/U	BB-2600/U
J-6587/P	5940-01-493-6750	BB-2800/U	
J-6589/P	5940-01-493-7622	NICKEL METAL HYDRIDE AA	
J-6588/P	5940-01-493-6751	MBITR (PRC-148)	
J-6769A/P	5940-01-544-3476	BB-2001A/U (CSEL)	
BTA-70715	TBA	FALCON (PRC-152)	
BTA-70774	TBA	IISR (PRC-153)	

Climatic Conditions: Operating: +14°F to +104°F is recommended. Accepted for short duration: -4°F to +122°F. Storage Temperature Range: -40°F to +158°F.

Notes: Requires periodic software upgrades as new adapters become available. For vehicle DC operation the DC cable must be ordered separately, J6362A/U, NSN 5940-01-501-6714.

EXTRACTS FROM TM 12359A-OD/B DATED AUGUST 2008

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APPENDIX F. MANUFACTURER'S DATA ON THE VEHICLE MOUNTED CHARGER

BATTERY CHARGER, VEHICLE-MOUNTED CHARGER (VMC)

NSN: 6130-01-527-2726	TAMCN: H6002	ID: 11100B

Functional Description

The Vehicle-Mounted Charger (VMC), PP-8481B/U, is the replacement for the Charger-On-The-Move (COTM). The VMC is designed for mounting in a tactical vehicle and provides forward area charging capabilities. The VMC charges two batteries at a time and automatically moves to the next two batteries in queue. The VMC comes with two Universal Adapters (J-6520A/U). Additional adapters are available but must be ordered separately. To avoid draining the vehicle battery, the VMC has a low voltage cutoff, which will stop battery-charging operations when low voltage is detected from the vehicle battery.

Technical Description

Battery Charger		Dimensions	
Manufacturer:	Bren-Tronics	Length (in):	27.0
Model:	PP-8481B/U	Width (in):	8.0
Input:	90-260 VAC or 22-28 VDC	Height (in):	14.0
		Weight (lb):	34.0
Frequency (Hz):	47-420	Volume (ft^3):	1.7
Warranty:	4 Years from MFG date	Operating Temp:	-4°F to +122°F
		Storage Temp:	-40°F to +158°F

Adapter	Adapter NSN	Battery	Battery
J-6520A/U	5940-01-493-8744	BB-2590/U	BB-390B/U
		BB-388A/U	BB-2800/U
		BB-516A/U	BB-326
		BB-2847A/U	MBITR (PRC-148)
J-6581/U (BULK)	5940-01-494-7116	BB-2590/U	BB-390B/U
J-6583/U *	5940-01-494-7118	BB-2001A/U (CSEL)	BB-2800/U
		BB-390/2590	BB-2847A/U
J-6584/U	5940-01-494-7120	BB-2557B/U	BB-557/U
		BB-2600A/U	
J-6585/U *	5940-01-494-3002	FALCON (PRC-152)	BB-2800/U
		BB-390/2590	BB-2847A/U
J-6585/U *	5940-01-494-4134	MBITR (PRC-148)	BB-2800/U
		BB-390/2590	BB-2847A/U

(*) Note: Requires software Version Program A.

Notes: Requires periodic software upgrades as new adapters become available. The Universal Adapter J-6520A/U is not interchangeable with the COTM Universal Adapter J-6520/U. Heating effects caused by AC power operation may degrade battery charge acceptance. The VMC comes with both an AC (CX-13553) and DC (CX-13554) power cables.

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APPENDIX G. MANUFACTURER'S DATA ON SPACES

TM 12359A-OD/B

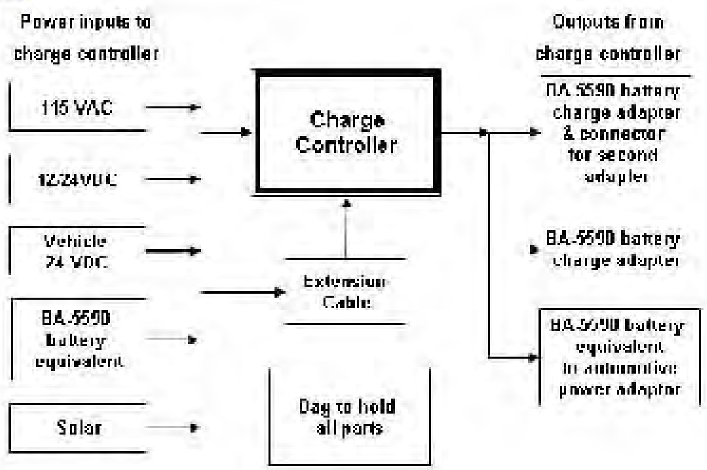
SOLAR PORTABLE POWER SYSTEM

NSN: TBD	TAMCN: TBD	ID: TBD

Functional Description

The Solar Portable Power System is a folding, portable solar panel system that provides energy to recharge BB-2590 batteries and to power external devices. The Charge Controller unit provides and uses various cable configurations to accept energy from different renewable energy power sources (DC/AC, Vehicle, Solar and BA-5590 Battery Equivalents). The Charge Controller unit converts renewable energy sources into a power output capable of recharging two BB-2590 Li-Ion batteries in 5 to 6 hours.

Parts Pictorial



Notes: The Solar Portable Power System is currently being evaluated. For additional information contact pm_eps@nmci.usmc.mil.

EXTRACTS FROM TM 12359A-OD/B DATED AUGUST 2008

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APPENDIX H. TABLE OF IRB SCENARIO CALCULATIONS

BA-5590					BB-2590					Analysis		
DOS	BA-5590 Qty (Ea)	BA-5590 Cost ($)	FBC BA-5590 ($)	BA-5590 Weight (lb)	BB-2590 Qty (Ea)	FBC BB-2590 Cost ($)	BB-2590 Cost Batts & Chrgrs ($)	FBC BB-2590 Batts & Chrgs ($)	BB-2590 Weight Batts &Chrgrs ($)	BB-2590 Weight Diff (%)	BB-2590 Weight Savings (lb)	Total FBC Investment Savings ($)
1	182	13,989	15,017	410	182	54,400	165,485	167,287	1,346	329%	(936)	(152,270)
2	364	27,977	30,034	819	364	108,800	218,083	221,687	1,928	235%	(1,109)	(191,653)
3	546	41,966	45,050	1,229	546	163,199	270,681	276,086	2,510	204%	(1,282)	(231,036)
4	728	55,954	60,067	1,638	546	163,199	270,681	276,086	2,510	153%	(872)	(216,019)
5	910	69,943	75,084	2,048	546	163,199	270,681	276,086	2,510	123%	(463)	(201,002)
6	1,092	83,931	90,101	2,457	546	163,199	270,681	276,086	2,510	102%	(53)	(185,985)
7	1,274	97,920	105,118	2,867	546	163,199	270,681	276,086	2,510	88%	356	(170,969)
8	1,456	111,908	120,135	3,276	546	163,199	270,681	276,086	2,510	77%	766	(155,952)
9	1,638	125,897	135,151	3,686	546	163,199	270,681	276,086	2,510	68%	1,175	(140,935)
10	1,820	139,885	150,168	4,095	546	163,199	270,681	276,086	2,510	61%	1,585	(125,918)
11	2,002	153,874	165,185	4,505	546	163,199	270,681	276,086	2,510	56%	1,994	(110,901)
12	2,184	167,862	180,202	4,914	546	163,199	270,681	276,086	2,510	51%	2,404	(95,885)
13	2,366	181,851	195,219	5,324	546	163,199	270,681	276,086	2,510	47%	2,813	(80,868)
14	2,548	195,839	210,235	5,733	546	163,199	270,681	276,086	2,510	44%	3,223	(65,851)
15	2,730	209,828	225,252	6,143	546	163,199	270,681	276,086	2,510	41%	3,632	(50,834)
16	2,912	223,816	240,269	6,552	546	163,199	270,681	276,086	2,510	38%	4,042	(35,817)
17	3,094	237,805	255,286	6,962	546	163,199	270,681	276,086	2,510	36%	4,451	(20,800)
18	3,276	251,793	270,303	7,371	546	163,199	270,681	276,086	2,510	34%	4,861	(5,784)
19	3,458	265,782	285,320	7,781	546	163,199	270,681	276,086	2,510	32%	5,270	9,233
20	3,640	279,770	300,336	8,190	546	163,199	270,681	276,086	2,510	31%	5,680	24,250
21	3,822	293,759	315,353	8,600	546	163,199	270,681	276,086	2,510	29%	6,089	39,267
22	4,004	307,747	330,370	9,009	546	163,199	270,681	276,086	2,510	28%	6,499	54,284
23	4,186	321,736	345,387	9,419	546	163,199	270,681	276,086	2,510	27%	6,908	69,300
24	4,368	335,724	360,404	9,828	546	163,199	270,681	276,086	2,510	26%	7,318	84,317
25	4,550	349,713	375,421	10,238	546	163,199	270,681	276,086	2,510	25%	7,727	99,334
26	4,732	363,702	390,437	10,647	546	163,199	270,681	276,086	2,510	24%	8,137	114,351
27	4,914	377,690	405,454	11,057	546	163,199	270,681	276,086	2,510	23%	8,546	129,368
28	5,096	391,679	420,471	11,466	546	163,199	270,681	276,086	2,510	22%	8,956	144,385
29	5,278	405,667	435,488	11,876	546	163,199	270,681	276,086	2,510	21%	9,365	159,401
30	5,460	419,656	450,505	12,285	546	163,199	270,681	276,086	2,510	20%	9,775	174,418

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